Low carbon innovation in China: from overlooked opportunities and challenges to transitions in power relations and practices

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Low Carbon Innovation in China: From Overlooked Opportunities and Challenges to Transitions in Power Relations and Practices

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Abstract (145/150 words)
This paper explores environmental innovation in the largest emerging economy – China - and its potential for contributing to global transitions to low-carbon, more sustainable patterns of development. It builds on earlier studies bringing alternative forms of low(er)-technology, 'below-the-radar', 'disruptive' and/or social innovation into its analysis. In addition, however, the paper develops our understanding of low-carbon innovation by paying particular attention to issues of changing power relations and social practices; theoretical issues that need attention in the literature generally but are notably absent when studying transitions in China. This shift in perspective allows four neglected questions to be introduced and, in each case, points to both opportunities and challenges to low-carbon system transition that are overlooked by an orthodox focus on technological innovations alone. These are briefly illustrated by drawing on examples from three key domains of low-carbon innovation: solar-generated energy; electric urban mobility; and food and agriculture.

Keywords: transition, innovation, low-carbon, China, power relations, practice

Introduction

Scientific studies of climate change and other planetary boundaries (Rockström *et al.*, 2009; Steffen *et al.*, 2015) suggest current forms of development risk taking us out of the ecological 'safe operating space', requiring broad systemic changes in order to avoid unpredictable impacts at a global level. These dramatic and rapid reductions in emissions are possible only by way of radical and globally extensive transformations in the socio-technical systems that shape the production and consumption of energy in all its forms. In early 2015, we see little evidence of the systemic changes needed to mitigate climate change and to deal with other environmental crises.

China is central to achieving such a transformation: energy demand has increased with the country's rapid economic growth, averaging 10% *p.a.* for 30 years, so that, given factors such as its high dependence on coal – China's coal-fired power sector is the world's largest single anthropogenic source of CO_2 emissions (Harris, 2010) – the country has become the world's largest absolute carbon dioxide emitting nation. Similar developments have been observed in total energy use, as demand in other sectors, such as agriculture and transport, have also seen high and increasing demand. Figure 1 shows just how dramatically China's electricity production has risen since 1970, and Figure 2 compares how CO_2 emissions have increased in recent decades in comparison to that in other countries.

Figure 1: Electricity production between 1970 and 2010 in China, billions kWh. Sources: World Bank, 2014 and IEA, 2014.

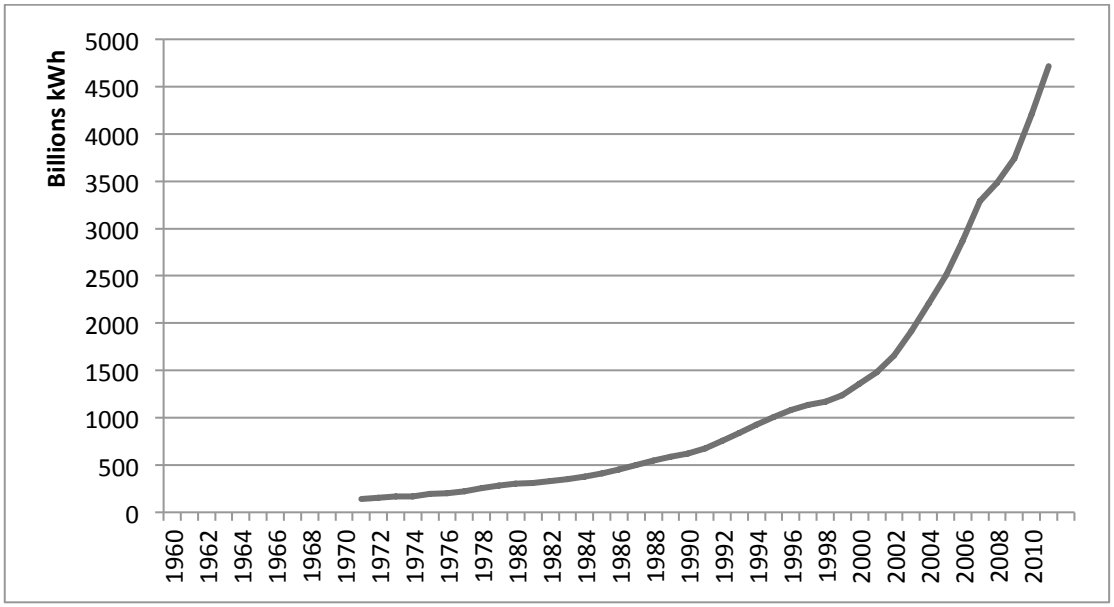
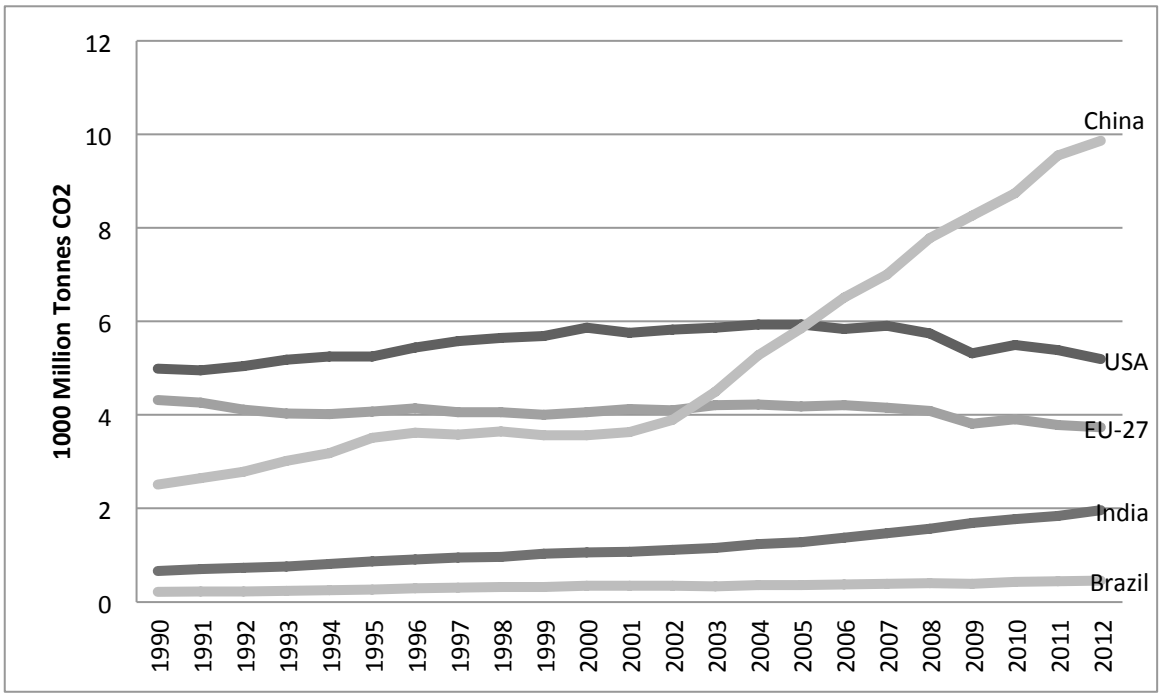


Figure 2: Total volume of CO_2 emissions from fossil fuel use and cement production for selected countries, 1000 million tonnes of CO_2, 1990-2012. Source: Netherlands Environmental Assessment Agency



A key question for scholars of the 'green transformation' is thus how such transformation can be achieved and maximally expedited (Schmitz 2015). Globally, the discourse of innovation has been put forward as a major way of 'fixing' climate change alongside broader arguments for developing 'sustainability-oriented innovation systems' (Altenburg and Pegels, 2012). Similar themes have been adopted in discussions of the 'entrepreneurial state' (Mazzucato, 2013), which stress the vital role of governments, not only in driving R&D investment in strategic 'green' sectors, but also in constructing a market for innovation and in building the skilled workforce required to serve emerging areas of eco-innovation.

Therefore, not only as the world's largest greenhouse-gas emitter, but also as the world's second-largest economy, China's potential transformation to a low-carbon, climate resilient or 'post-carbon' society is a key concern for the world. This paper, based on early indications from our research in three key sectors – food and agriculture; energy; and urban mobility – finds that this transformation is still overwhelmingly conceptualized in terms of the opportunities regarding 'high-technology' innovation at the technological 'frontier'; a narrative that resonates with techno-nationalist calls from the Chinese leadership for 'indigenous' or 'independent' innovation as a driver for competitiveness and growth (Jakobson, 2007, Zhao 2010). This paper offers a different understanding of innovation that promises to be more productive in that it signals both opportunities and challenges that the high-technology-focussed approach overlooks.

Instead, this approach explores the complex, systemic and emergent nature of the multiple processes involved in transition. In particular, going beyond existing systems transition literature, this involves a re-insertion and reconceptualization of power in the process of low-carbon transition, and greater attention to the role and habituated practices of societal actors, including users and producers. As such, both opportunities and challenges to low-carbon transition, and particularly in the context of ongoing (national) projects of development 'catch-up', emerge along four dimensions. These concern the potential systemic importance of:

1. Bottom-up, emergent vs. top-down co-ordinated innovation and transition governance (Smith et al 2005);
2. Low(er)-technology, 'below-the-radar', 'disruptive' or 'frugal' innovations vs. hi-tech innovation (Kaplinsky 2010, Breznitz and Murphree 2011);
3. Social vs. technological aspects of innovations (Smith and Ely 2015); and,

4. Innovation demand vs. supply (Bhidé 2009).

This heuristic serves to highlight the potentially significant but neglected contribution to expedited system transitions of forms of innovation that may be both particularly appropriate and effective in fast-developing societies such as China (and the other 'emerging economies'). It is also used to present our preliminary findings, as summarised in Figure 3.

Figure 3: Overlooked Challenges and Opportunities Across 4-Dimensions of Low-Carbon Innovation in China – Examples from Agri-food, Solar energy and E-mobility

	Challenges	***Opportunities***
Bottom-up/Top-down	Green public sphere, crucial for management and driving of low-carbon innovations, is limited.	Significant state resources (*Cf* Mazzucato 2013) could be deployed to support and develop existing bottom-up 'indigenous' successes.
Low-tech/High-tech	Low public trust and complex politics around the approval of R&D-intensive, high-tech agricultural approaches.	Considerable consumer demand and institutional innovation in the areas of agro-ecological approaches to agriculture and food.
Social/Technological	Multiple barriers to installation of solar PV modules, without attention to cost, local grid capacity and social practices.	Much to learn from existing 'demand' successes in the successful diffusion of solar water heaters: low-cost standalone systems that have not benefited from central state support.
Demand/Supply	EV/E2W alike are at best niches, not system transitions, without significant consumer appeal in context of social politics of autonomy and status.	Existing 'demand' successes could be supported, e.g. by developing the E2W as basis of wholly new, equitable and locally-relevant urban mobility system.

Preliminary findings

1. Bottom-Up and Top-Down

The benefits of attending to changing social practices and power relations in Chinese low-carbon innovation can be illustrated by studying its politics, by which we refer not only to laws and changes in formal institutions of government but the full complex system of dynamic power relations constitutive of the field.

Historically, China's national Five-Year Plans (FYPs) have played a key role in setting the country's key strategic, economic and innovation priorities, with the Sixth FYP (1981-1985), at the start of China's Reform Era, being the first to include energy conservation efforts – around the same time that China passed the first of its environmental laws and regulations. The 9th Five-Year Plan (1996-2000) was the first to include the term sustainable development (Geall and Pellisery, 2012), and in 1997, the 15th Party Congress listed the 'huge environmental and resource pressures caused by population growth and economic development' as major difficulties facing the Chinese population.

More recently, tackling climate change has become increasingly central to (central) government agendas. China published the first national climate-change plan of any developing country in 2007, which formalised China's commitment to addressing climate-change mitigation and adaptation, while also upholding the principle of 'common but differentiated responsibilities' and integrating climate change into other policies for national and social economic development – thus establishing that climate policies do not take priority over other national objectives (Harris, 2010). Climate change is also emphasised in the 12th Five-Year Plan (for 2011-15) (NDRC, 2011), which lists seven strategic emerging industries for support – including environmental protection & energy efficiency, new energy, biotechnology and clean-energy vehicles – and pledges a reduction in energy consumption per unit of GDP (energy intensity) by 16%, a carbon intensity reduction of 17% and a target for non-fossil fuel to account for 11.4% of primary energy consumption.

China, despite dramatic transformations in its socio-economy and associated power relations, remains effectively a one-party state. The result has been a variant of 'state capitalism' (e.g.

Huang, 2008; Tsai, 2007). Although privatisation of state-owned enterprises (SOEs) has proceeded apace since the 1990s (WB/DRC, 2012), the political economic domination of major SOE national champions and the associated 'cadre-capitalist alliance' (So 2003) of top party-state leaders and SOE managers has 'reached a new peak in recent years' (Zhang, 2011: 148). In 2009, the total profits of two giant SOEs (Sinopec and China Mobile) were larger than those of the largest 500 private companies. State-owned companies account for 80% of the stock market, including the three largest companies by revenues (all in the Global Fortune top 10). Nominally 'private' companies, especially national champions, are closely connected with state institutions. This also profoundly affects innovation policy, which is targeted to the techno-nationalist development of the global competitiveness of the largest and most-technologically advanced SOEs as forms of 'indigenous innovation' (*zizhu chuangxin*) in the hope of moving 'up the value chain' while (and/or as means of) preserving the party-state political regime (Zhao 2010).

Since 2006, the central government, as buyer and seller in key industries, has introduced stringent, complex and fast-changing regulations on high-tech foreign enterprises mandating high local-content requirements and transfer of proprietary technologies (Hout and Ghemawat, 2010). Through a suite of policies and investments, the country has managed to build (or acquire) world-leading firms in strategic 'green' sectors such as manufacturing solar panels and wind turbines (Lema and Lema, 2012). However, economic decentralisation has played an important role in unleashing these forces during the Reform Era. Rather than being a monolithic system, China's governance of science, innovation and environmental decision-making in the Reform Era – the 'state' of its 'state capitalism' – has been characterised by 'fragmented authoritarianism', with protracted bargaining between bureaucratic units, including ministries, advisory bodies and top-level 'National Leading Groups' (Heggelund, 2004), as well as horizontal fragmentation between levels of government (Economy, 2005). Recent Chinese observers of the effects of this decentralisation note the extent to which a 'project system' logic has been instituted across government at all levels: a 'governance model between the traditional system and market mechanisms' (Tian, 2014: 1) where local governments compete for projects to attract special funding from central government.

While the 'ideological foundation' of such a system is technocratic (Tian, 2014: 3), its 'expert rationality' often acts instead as 'cover for sectoral interests and interest groups'. In practice, writes Kelly (2014: 57) such an arrangement: 'produces governance that sits uncomfortably

half-way between full-scale planning signed off by ministers and the flexibility and canny differentiation of the market.' The result is compromised dynamics of innovation, with many top-down government innovation projects (e.g. in EVs and the building of associated charging infrastructures) adopted at best half-heartedly by SOEs and/or local governments tasked with the 'implementation' of innovation plans. Moreover, the political dominance of incumbent Chinese 'carbon (state) capital' in a system of innovation that remains so highly politicised and dependent on close connections with state institutions significantly hinders the emergence of potentially system-disruptive low-carbon innovations.

Conversely, non-governmental actors, institutions and discourses have greater sway over decision-making around environment, climate change and innovation policies than in previous eras. Over the past two decades, citizen oversight, media coverage and other forms of public participation by civil society have been given greater space to improve the local enforcement of environmental regulations in the context of waning state capacity for such governance. While many of China's institutional procedures for public participation and environmental transparency are vague and poorly enforced, environmental NGOs have proliferated (e.g. 492,000 legally registered social organisations, according to a 2012 government report, of which many are 'green') and a '*green* public sphere' has emerged (Calhoun and Yang, 2007, our emphasis). Concerns about environmental issues have increased among China's newly enriched middle class, with opinions expressed more freely and rapidly than ever before due to increasingly ubiquitous social media and messaging technologies. Urban protests increasingly focus around the lack of transparency and accountability concerning potentially polluting developments (Geall and Hilton, 2014), and according to some in the Chinese government, they represent the most common catalyst for 'mass incidents' or protests.

The emergence of a ('bottom-up') green public sphere is arguably crucial for power momentum behind any low-carbon transition, and for the development of the social capacities to manage and drive forward further low-carbon innovation (Smith and Ely 2015). Yet it is still merely tolerated in China and in perpetual threat of clampdown (Jacobs and Buckley 2015). The emergence and strength of a green public sphere is thus a key challenge. However, a major opportunity for Chinese low-carbon innovation illuminated by this perspective is the possibility of a fusion of approaches, whereby the state could deploy its significant resources (institutional, human resource, technological, financial etc…) to give

transformative top-down support and massive infrastructural direction to the accelerated *further* innovation of what are *already* bottom-up, if 'low(er)-tech', innovation successes in China. This leads to the second and third set of issues.

2. Low(er)-tech & high-tech approaches

In the domain of agri-food systems (Ely *et al.*, 2014) initial research indicates that higher-tech approaches to low-carbon innovation have so far overlooked some of the social, political and demand-side barriers to a coordinated, sustainability-oriented transition. The dominant focus of 'low-carbon innovation' in Chinese agriculture have been supply-side measures, such as the centrally-supported development of genetically modified phytase maize as a potential component of intensive, high external input agriculture and livestock systems. Phytase is an enzyme that when added to maize facilitates the absorption of phosphorous in monogastric animals like pigs. If effective, transgenic high-phytase maize could reduce the requirement for land or fertiliser for any particular meat yield, given the higher bioavailability of phosphorus.

However, early indications are that low levels of public trust and significant political disagreement have been an unforeseen factor in creating significant delays in the renewal of the biosafety certificate for phytase maize by the Ministry of Agriculture after it expired last year. Public debates about food safety in China are characterised by "extreme anxiety and uncertainty" (FORHEAD 2014: 53–4) and our research seems to confirm Keeley's (2005: 157) observation that China's 'embrace of the biotechnology revolution [was] not as unequivocal as much global discourse suggests', particularly among end consumers.

Concurrently, initial research indicates that "lower-tech" alternatives exist in the agri-food domain that could be better explored with greater attention to politics and practice. The growth of low external input and organic community-supported agriculture (CSA) farms around first-tier cities in China; new networks connecting farmers and consumers, often enabled through digital communications technologies, such as the Beijing Farmers Market, or the Farmers Seed Network, which has encouraged seed saving and traditional forms of seed exchange in rural Guangxi, as well as retail direct from small-scale producers to "ecological" restaurants in the provincial capital Nanning; and online retail for low-volume, high-quality specialised organic food commodities, all indicate how changing social relations –

particularly with regard to China's emerging middle class(es) – might enable new kinds of 'bottom-up', lower-tech innovation alternatives that could avoid the sorts of high-carbon lock-ins and rebound effects that are likely to result from greater intensification of China's livestock system.

3. Social & technological aspects

In the field of solar-generated energy (Urban and Geall, 2014), initial research indicates that despite China having become the world's largest investor in solar photovoltaics – an IP- and R&D-intensive industry that the Chinese government has centrally supported and is now the world's largest investor, producer and exporter – systemic barriers to the installation of solar PV modules remain. Many, though not all, of these barriers have social, rather than technical, components, and these include: grid connectivity and reform, since certain policies, such as capacity-based subsidies, have driven the construction of renewable energy infrastructure without matching grid connectivity, and policies such as Feed-in-Tariffs (FiTs) have assumed higher levels of knowledge and monitoring capacity on the part of electricity consumers and local grids, respectively, than currently exists; property rights, since some approaches, including FiTs, assume energy users own their own properties or roof-spaces to install PV modules; and cost, given the relatively large up-front cost of a PV module and related costs associated with installation and replacement of sometimes unreliable supporting components, such as inverters. Conversely, in the case of solar water heaters – where fewer of these barriers exist – China has the world's largest installed capacity (REN21, 2012). These low-cost standalone systems have not only been very popular, and therefore constitute largely undiscussed agents in the transition from fossil fuels to low-carbon energy, but also indicate where closer attention to social aspects and elements of practice could point to previously unexplored potential drivers and pathways for disruptive, low-cost and low-carbon innovation.

4. Demand & supply

Finally, as regards the issue of demand for innovation, perhaps the clearest example of this key issue in Chinese low-carbon innovation emerges from comparison of the electric vehicle (EV, i.e. electric car) and the electric two-wheeler (E2W, or e-bike) (see Tyfield, Zuev *et al.*,

2014). The former is the beneficiary and focus of amongst the most ambitious and concerted programmes of national industrial policy in the world for EV transitions, while the latter receives effectively no government support and is officially banned in many cities.

Yet E2Ws are effectively ubiquitous in Chinese cities (even those with the municipal bans), numbering some 180 million on recent estimates, while EVs are struggling to achieve any sales beyond those bought through programmes of government procurement for taxi companies. The key issue here is that the EV has effectively no attraction to possible consumers, even with significant purchase subsidies and other financial perks, being seen as a relatively expensive but utterly unglamorous car. As such, the EV is in competition with premium, foreign (particularly German) conventional cars; vehicles, moreover, that are the focus of a consumer desire that is much more than mere utility 'preference' but bears the weight of a profound social thirst for experiences of personal autonomy and status competition that are vested specifically in consumer choices. Conversely, the E2W is a cheap, convenient and overwhelmingly indigenous technology that offers to the majority of the population the possibility of faster, cheap and utilitarian mobility.

In these circumstances, therefore, focusing on demand, not just supply, from a perspective of changing power relations and social practices suggests that the EV has little prospects of catalysing a system transition in urban mobility on its current form – basically, a standard car with a different engine. Nor will Chinese car companies likely succeed in achieving a new global dominance on the back of their mastery of this technology. The key challenge, rather, is for a Chinese EV to be developed that has unquestionable market appeal – whether directly targeting the wealthy (such as in the case of Tesla) or offering a different prospect of urban mobility that makes the EV unquestionably more cost- and time-effective. Conversely, a key opportunity thus highlighted returns us to the point made above regarding the potential for the Chinese state to throw its full weight behind the development of an entirely new model of urban mobility based upon (indigenous) E2Ws and their further innovation into new, compact and lightweight vehicles.

Thus, in all three domains, the profoundly systemic nature of the transition required – in how China eats, moves and heats and powers its homes – and the complex interdependencies involved in such changes, warrant a greater focus on wider options beyond high-tech, on the dynamics of bottom up vs. top down, on social aspects and ultimately on the multitude of

users on the demand side. These are only some of many preliminary possibilities, which we will also be exploring further in the course of our research. However we also now place them within the wider literature in order to better discuss these initial findings.

'High-Tech' Innovation and its Limitations

In 2014, in a speech to the Chinese Academy of Sciences (CAS) and Chinese Academy of Engineering (CAE), China's President Xi Jinping stated that: 'the direction of China's science and technology development is "innovation, innovation and innovation"' and noted that 'independent innovation' should be the 'essence' of a strategy to 'free up the huge potentials of science and technology' (Xinhua, 2014). The same sort of high-tech focus is evident in what is now a large and rapidly growing literature on low-carbon innovation in China that documents impressive developments regarding some renewable technologies such as wind energy, solar photovoltaics, hydropower and electric vehicles (EVs).

Scholars have begun to adopt an innovation systems approach to investigate the role of policies, firm strategies and university-led R&D in building China's eco-innovation capabilities (Altenburg and Pegels, 2012) and the prospects of success of 'indigenous innovation' policies in the current form and focus. Some authors have questioned how quickly the country's firms can come to a position of dominance, describing the journey towards eco-innovation leadership as a 'hard slog' rather than a 'leapfrog' (Rock *et al.*, 2009). Others, drawing from examples in coal-fired electricity generation, cement production and electric vehicles have pointed towards China as an example of how developing countries can adopt a strategic approach to building low-carbon technological capabilities within domestic firms (Watson *et al.*, 2014).

Lema and Lema (2012) have analysed the shift from conventional 'technology transfer' to joint ventures and technology acquisition by Chinese (and Indian) firms in the wind energy industry and, working with other colleagues, Lema analysed in detail how Chinese wind power firms impacted on global value chains by component suppliers (Lema *et al*., 2013). Drawing on technological innovation systems approaches, Gosens *et al*., (2013) investigated learning in clean-tech innovation. Fischer (2012) has provided detailed accounts of the technology, policy and political barriers and challenges that characterised the Chinese PV sector, while Dai (2014) conducted political analyses of wind energy policy at national and

local levels of government. Our findings confirm the value of these studies, but raise further questions about the role of power and practices, pointing to important future research.

In particular, while they provide certain insights into the politics of innovation policy, they still focus primarily on the supply side, or, like the 'transition studies' literature in general (Geels, 2002 – see next section), treat the demand side from an economic, 'market' perspective. As such, while they provide a good basis for understanding industrial development in these strategic sectors, with a few exceptions, they engage less with political and sociological questions of transition (though see Geels, 2014). The result is that where these qualitative issues are especially important and/or fraught, insight is diminished; yet this is precisely the case regarding both transition to low-carbon 'economy-and-society' (Urry, 2011) and in China in particular.

'Practices' and 'Power': Neglected Areas in Chinese Low-Carbon Innovation and Transitions

The socio-technical transitions literature opens a much more detailed, nuanced and informative analysis of the processes and progress of low-carbon innovation in China than a techno-centric approach. Yet two crucial aspects to the 'social' (and hence socio-technical) nature of innovations are:

- the process of successful and widespread demonstration and deployment of an innovation beyond a specialised niche, through underlying social practices and their transformation (Smith *et al.*, 2010); and,
- whence the dynamism behind any successfully emergent system innovation, and its social provenance and character (Tyfield, 2014).

These remain under-developed in the literature on low-carbon innovation in general, with significant analytical cost, but are particularly evident gaps when analysing low-carbon innovation in China. Our approach places these considerations at centre-stage, in terms of concerted empirical and theoretical attention to the issues of social practices and power relations respectively.

As regards the former aspect, most analysis of low-carbon innovation in China focuses upon issues of production. The reception and consumption of innovations, including changes in associated social practices (Shove and Walker, 2010), is largely neglected. Social practice theorists critique the notion that behaviour (and potential behaviour change) can be understood as rational, cognitive individual processes, highlighting how practices are social, loaded with social meaning, affect and identity, habitual or routinised, systemically-situated and performative.

Such an approach sees social practices not only as mediating many of the relationships between the elements in socio-technical transitions, but also as ordering and orchestrating the interactions between them in a 'nexus' of practices (McMeekin and Southerton 2012). Thus reconfiguring practices around a particular technology can actually lead to changes in other interlocking habits, opening up opportunities for new innovations to emerge and play a reinforcing or steering role in niche or pathway development. This is particularly important in China, where the disruption of economic reforms, urbanisation and other social and environmental changes are in turn destabilising habitual routines for many people. Evidence from the electric vehicles case illustrates quite clearly that cultural meanings, such as social status, have an effect on practices, which are undergoing significant change and are the arena of affective efforts by Chinese citizens seeking new meanings and identities amidst change.

The dynamic interplay between power relations and transitions, while its central importance has long been recognised (Smith *et al.*, 2010), is far from well understood. There are actors who are committed to, and are likely to benefit from, significant systemic changes involved in any transition process, and often organise to try to bring it about (Smith, 2007). Yet the systemic complexity of socio-technical transitions means they are unlikely to emerge according to the blueprint of any single (set of) actor(s).

Studies of the politics of transition in Europe have begun to study these processes by looking at the interests and institutions concerned (e.g. Kern, 2011; Lockwood *et al*., 2013). But generally conceptualized in terms of given institutions, interests and structural inequalities in access to resources – amounting to 'techno-institutional lock-in' (Unruh 2000) – most of this literature tends both to illuminate only the structural difficulties facing emerging systems transitions, rather than strategic openings, and to take as given the basic institutional forms of politics and decision-making. However, ignoring openings lessens the potential for insights

that could expedite low-carbon transitions; and the politics of decision-making are also under intense pressure to change from the profound socio-political challenges of responding to global climate change.

Both of these overlooked aspects – strategic openings, on the one hand; and changing power relations, on the other – are inescapably important issues when studying low-carbon innovation in China: first, because the need to avoid high-carbon lock-in is particularly pressing; second, because many of the institutions of liberal democratic governance are absent or ineffective in China, and because the country's low-carbon innovation policy and strategy has arguably as one of its *goals* the global transformation of geopolitical relations, through the mastery of key technologies. Early indications from this research therefore suggest that power might be conceptualised as not only structural and 'locked-in' (Tyfield, Ely *et al.*, 2014) but also as "world-productive". This suggests that systems could be redefined as complex dynamic systems of power relations mediated by socio-technologies, the generation of which, in turn, conditions changing and newly enabled or constrained power relations. As summarized in Figure 4, this suggests an intelligible and empirically researchable conceptualisation of positive feedback loops of accelerating and deepening system-shifting innovation – a 'power momentum' of system emergence – where low-carbon transition is a *power transition,* albeit one that may unfold over several decades (*Cf* Arthur 2009).

Figure 4: Two Step Analysis of Emergence of a Power Socio-Technical Transition

In both Figures 4a and 4b, the model schematically describes the process of transition emergence as a strategic power relational process. Bold arrows denote the analytical focus of the step, while dotted lines denote processes understood to be happening but which are abstracted from for the purpose of this specific step in the analysis.

Figure 4a: Step 1

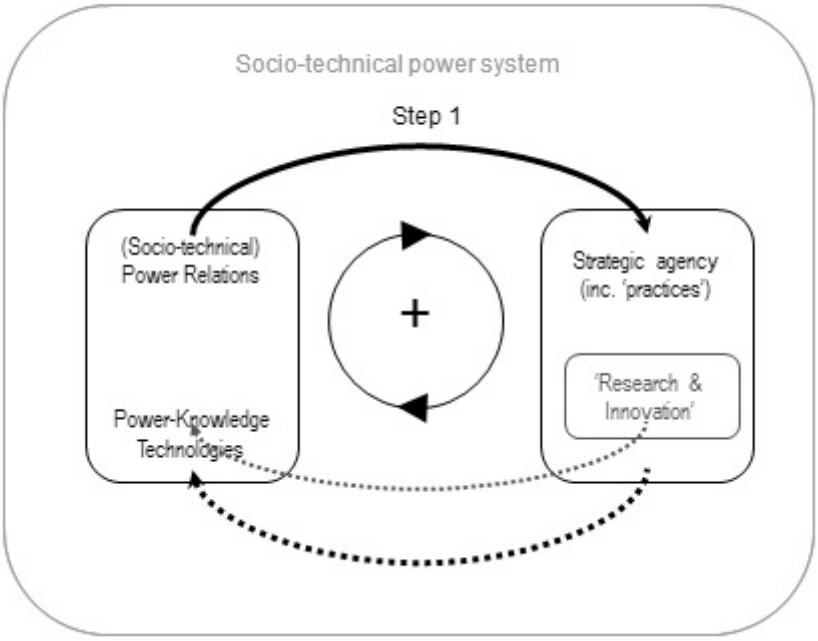
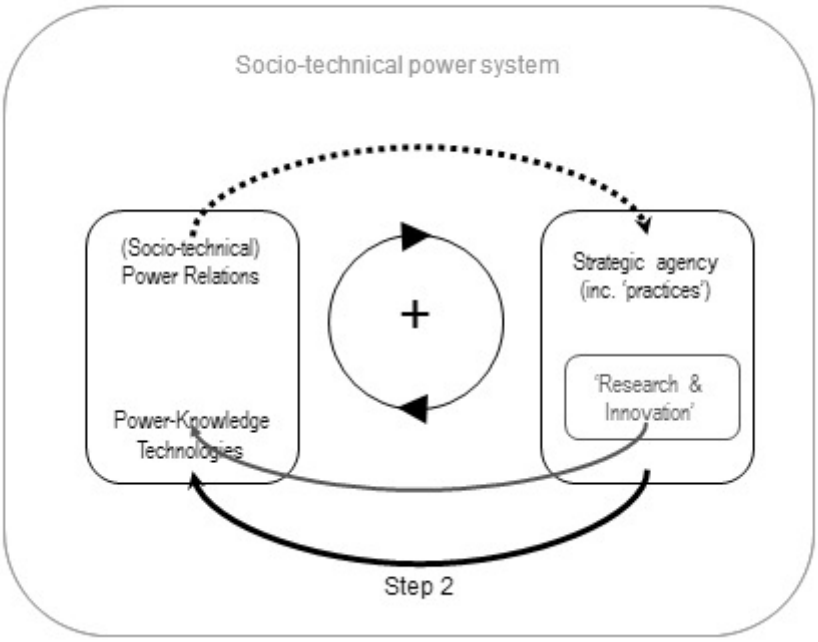


Figure 4b: Step 2



Reconceptualizing transitions in this way thus affords a frame through the four heuristic dimensions discussed above may be not only re-introduced as central issues, but also understood and interrogated in terms of a both/and, rather than either/or, logic in respect of each dualism. The key questions, in other words, become *'how* exactly do issues of top-down *and* bottom-up (supply *and* demand etc…) innovation interact at present?; how could they do so more productively, equitably and sustainably?; and with what broader implications regarding the power-relational character of societies?'

Conclusions

This paper has argued that low-carbon innovation in China represents an important case study of innovation's potential to contribute to more sustainable patterns of development. Drawing on examples from ongoing empirical work, we show how a framework attentive to issues of changing power relations and social practices can improve our understanding of low-carbon innovation in China and highlight both challenges and opportunities missed by mainstream analysis. As such, it highlights how low-carbon innovation in China could be a site of significant promise and opportunity even as high-profile projects of high-technology innovation continue to struggle to seed low-carbon systems transitions.

In all three domains discussed (solar energy, electric urban mobility and agri-food), the profoundly systemic nature of the transition required – in how China eats, moves and heats and powers its homes – and the complex interdependencies involved in such changes (including across these domains), means that any low-carbon transition is likely to have far-reaching consequences and will occur in parallel with wider changes in Chinese society, culture and politics. Social and political decisions and trajectories could result in a number of different low-carbon scenarios: some in which inequality and social unrest continues to deepen, for example, and others where 'bottom-up' or 'disruptive' innovation is harnessed for poverty alleviation, or are even socially or politically disruptive in ways that affect existing power structures, including those bound up with Chinese 'carbon (state-) capital'. These are some of many preliminary findings that we will be exploring further, in the course of our research.

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